A DEVELOPMENT OF IOT BASAL BODY TEMPERATURE (BBT) DEVICE WITH OVULATION AND PREGNANCY PREDICTION SYSTEM USING FUZZY LOGIC METHOD

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Special dedication to…

My beloved father and mother
(Mohd Yazed Bin Othman & Siti Jurinah Binti Salamon)
for the inspiration and care.

My family for their support and love.

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And those who have helped and supported me.

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ABSTRACT

Fertility Awareness Method (FAM) is a natural family planning method that is based on body signs, commonly basal body temperature (BBT) changes during each menstrual cycle in response to hormonal changes in a woman's body. There are several products on the BBT devices that can help in charting, monitoring, and tracking the fertility automatically. However, most of them are less used for a consultation purpose because of time-consuming to meet the physician. Besides, the products are lack of clinical studies being reported on the algorithm used to derive the information needed for fertility monitoring. Therefore, this research has developed a prototype named TempIoT1.0 which is a BBT device that's equipped with a smart fertility prediction using fuzzy logic intelligence computational method that can predict ovulation and pregnancy. This prototyped has been integrated with an Internet-of-Things (IoT) for automatic BBT charting and monitoring and accessible data sharing for consultation through an Android application. The smart fertility prediction system has been verified on 60 datasets of the BBT cycles that give an accuracy of 78.3% and 95% for ovulation and pregnancy prediction, respectively. Through performance evaluation of TempIoT1.0 with Omron and iBasal on a healthy subject, comparable results in terms of BBT data pattern with a correlation of 0.984 and 0.972, respectively were observed. TempIoT1.0 is comparably able to predict the occurrence of the ovulation with 67% similarity in the prediction of the ovulation phase and 100% similarity in the prediction of pregnancy. In conclusion, TempIoT1.0 could enhance women’s understandings of their own unique menstrual cycle in a deeper level towards a better healthcare and to the best of found knowledge, this will be among the leading IoT device for the automatic BBT charting and monitoring with a smart fertility prediction system.

ABSTRAK

Kaedah Kesedaran Kesuburan (FAM) adalah kaedah perancang keluarga semula jadi yang berdasarkan isyarat tubuh, perubahan suhu badan asas (BBT) pada setiap kitaran haid sebagai tindak balas terhadap perubahan hormon dalam tubuh wanita. Terdapat beberapa produk peranti BBT yang boleh membantu dalam mencatat, memantau, dan menjejaki kesuburan secara automatik. Walau bagaimanapun, kebanyakannya kurang digunakan untuk tujuan perundingan kerana memakan waktu untuk memenuhi perundingan. Selain itu, produk peranti tersebut kurang kajian klinikal yang dilaporkan bagi algoritma yang digunakan untuk memperoleh maklumat yang diperlukan untuk pemantauan kesuburan. Oleh itu, kajian ini telah membangunkan satu prototaip bernama TempIoT1.0 yang merupakan peranti BBT yang dilengkapi dengan ramalan kesuburan pintar menggunakan kaedah pengiraan kecerdasan logik fuzzy yang boleh meramalkan ovulasi dan kehamilan. Prototaip ini telah diintegrasikan dengan Internet-of-Things (IoT) untuk mencarta BBT secara automatik dan pemantauan dan perkongsian data yang boleh diakses untuk perundingan melalui aplikasi Android. Sistem ramalan kesuburan pintar telah disahkan pada 60 dataset kitaran BBT yang memberikan ketepatan 78.3% dan 95% untuk ovulasi dan ramalan kehamilan, masing-masing. Melalui penilaian prestasi TempIoT1.0 dengan Omron dan iBasal menggunakan subjek yang sihat, hasil pemerhatian yang boleh dibandingkan dari segi pola data BBT dengan korelasi masing-masing 0.984 dan 0.972. TempIoT1.0 adalah sebanding untuk meramal terjadinya ovulasi dengan 67% keseragaman dalam ramalan fasa ovulasi dan 100% keseragaman dalam ramalan kehamilan. Kesimpulannya, TempIoT1.0 dapat meningkatkan pemahaman wanita tentang kitaran haid mereka yang unik dalam tahap yang lebih mendalam ke arah penjagaan kesihatan yang lebih baik dan pengetahuan yang terbaik untuk dijumpai, ini akan menjadi peranti IoT yang terkemuka untuk mencatatkan dan mengawasi BBT automatik dengan sistem ramalan kesuburan bijak.

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LIST OF SYMBOLS AND ABBREVIATIONS

Ω/℃	-	Ohm / degree Celcius
3D	-	Three Dimension
2G	-	Second Generation
3G	-	Third Generation
A	-	Ampere
ANN	-	Artificial Neural Network
API	-	Application Programming Interface
AWS	-	Amazon Web Services
BBT	-	Basal Body Temperature
CEO	-	Chief Executive Officer
CI	-	Computational Intelligence
CM	-	Cervical Mucus
DA	-	Data Access
DSS	-	Dassault System
DWG	-	Data Working Group
FAM	-	Fertility Awareness Method
FIS	-	Fuzzy Inference System
FSH	-	Follicle Stimulating Hormone
GE	-	General Electric
HTTP	-	Hypertext Transfer Protocol
HTTPS	-	Hypertext Transfer Protocol Secure
iBasal	-	intelligent digital Basal thermometer
IC	-	Integrated Circuit
IDE	-	Integrated Development Environment
IEEE	-	Institute of Electrical and Electronics Engineers
I/O	-	Input / Output
IoE	-	Internet of Everything

iOS	-	iPhone Operating System
IoT	-	Internet of Things
IP	-	Internet Protocol
IUD	-	Intrauterine Device
KB	-	Kilo bytes
LAN	-	Local Area Network
LCD	-	Liquid Crystal Display
LED	-	Light Emitting Diode
LiPo	-	Lithium Ion Polymer
LH	-	Luteinising Hormone
LTE	-	Long-Term Evolution
M2M	-	Machine to Machine
MAC	-	Media Access Control
MATLAB	-	Matrix Laboratory
MB	-	Mega bytes
MCU	-	Microcontroller Unit
MIT	-	Massachusetts Institute of Technology
NFP	-	Natural Family Planning
NTC	-	Negative Temperature Coefficient
OLED	-	Organic Light Emitting Diode
OPC	-	Open Platform Communication
OS	-	Operating System
OTA	-	Over-The-Air
PC	-	Personal Computer
PCOS	-	Polycystic Ovarian Syndrome
PHY	-	Physical Layer
PLC	-	Programmable Logic Controller
PMS	-	Premenstrual Syndrome
PSTN	-	Public Switched Telephone Network
PWM	-	Pulse Witdth Modulation
RAM	-	Random Access Memory
RF	-	Radio Frequency
RFID	-	Radio Frequency Identification

RTD	-	Resistance Temperature Detector
SCL	-	Serial Clock Line
SDA	-	Serial Data
SI	-	Swarm Intelligence
V	-	Volt
VIN	-	Input Voltage
WEKA		Waikato Environment for Knowlegde Analysis
Wi-Fi	-	Wireless Fidelity
WLAN	-	Wireless Local Area Network
WSN	-	Wireless Sensor Network
uA	-	Microamperes
USB	-	Universal Serial Bus

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter will explain about the basic of the research, which includes research background, problem statement, aim, objectives, and project scope.

1.2 Research background

Family planning involves the responsibilities of husband and wife to make a decision on the timing of having a child and the number of children to have [1]. This is important for the health and safety of the mother and child. Each family has the right to have the number of children they want, but the distance between one child and the other can be planned using family planning methods. An effective family planning is important in reducing the danger of maternal mortality, increasing the health of the children and allowing the women to be more in control of their fertility in order to improve or reduce the probability of pregnancy [2]. There are five types of family planning methods such as barrier method, hormonal method, intrauterine device (IUD) method, natural method, and also a permanent method that are discussed more in Chapter 2. In short, these five types of family planning methods can be classified into two general methods. The first method is the natural method or called Fertility Awareness Method (FAM), and the second method is the medical treatment method that consists of barrier method, hormonal method, intrauterine device (IUD) method and permanent method [3].

FAM is a family planning that based on fertility body signs [4], for examples Basal Body Temperature (BBT), and cervical position and mucus, which change

during each menstrual cycle in response to the hormones that cause ovulation [5]. While medical treatment method involves hormone medicine and also surgery [5]. The use of medication and surgery in planning the fertility can cause health problems to the couple especially the woman. Using medication could initiate a complication such as spotting or irregular periods, nausea (feeling sick at the stomach), headaches, mood changes (feeling down), breakouts (get acne), sore or bigger breasts, gain or lose weight, and imbalance human hormones [6]. The surgery method is costly and may not be reversible and it can be vulnerable to illness. Due to expensive cost of medical treatment method compared to the FAM, most of the obstetricians recommend the couple to use FAM especially the BBT technique. BBT is safe and not a disgusting technique compared to checking the cervical mucus and position. This method is done by plotting the women's body temperature which are measured in the early morning everyday [7]. Charting BBT over the course of the menstrual cycle in women is a low cost and a safe approach to monitor the trends of body temperature in a cycle and it is strongly recommended by many obstetricians and gynecologists in order to identify ovulation disorders in female fertility as early stage [8].

However, charting of the body temperature every morning is tiresome to some people [2]. Although there are several BBT gadgets these days that can plot body temperature automatically and monitor the ovulation graph in a convenient way, for example, Wink Kindara, Yono Fertility, Tempdrop, Duo Fertility, and Ava Bracelet, these gadgets use an application to predict the fertility where these devices will connected the BBT data through Bluetooth. Besides, they are more focusing on private used not for consultation, [5, 9, 10]. The details of these products are discussed in Chapter 2. Moreover, there are only few previous studies working on a smart fertility prediction based on the BBT data in order to understand the menstrual cycle for the women healthcare. Thus the implementation of computational intelligence for fertility prediction system in order to understand the menstrual cycle has been developed in this research.

Nowadays, the Internet of Things (IoT) has been an emerging technology in collecting and monitoring meaningful data for further analysis which in turn could lead to cost-saving measures. The IoT is referred to cloud connected things or devices with sensors which based on four hierarchies of functions. These four hierarchies start with monitoring the data, controlling data using function personalised by developer, optimisation which can enhance the monitoring performance, and lastly the

autonomous, the system that can self-coordinated and auto operated between monitoring, controlling and optimisation [11]. In present day, there are numerous IoT applications which are implemented for smart city development, smart manufacturing, autonomous vehicle, and healthcare. In the IoT healthcare solutions, there are a lot of applications, for examples tracking all-day activities, exercise, sleep, heart rate, blood pressure, glucose level, and fitness [12, 13].

Along these lines, through this study, a BBT measurement, automatic charting and monitoring, and smart fertility prediction system called TempIoT1.0 has been developed. TempIoT1.0 was developed using a Particle Photon integrated with fertility prediction system which based on the BBT data. TempIoT1.0 has been inspired by fuzzy logic computational intelligence system that can be stored in Google Spreadsheet as the IoT cloud storage platform in order to create a medium of sharing data for the monitoring and specialist advice purposes; where the information can be shared in a secure environment. The BBT was measured using a contact temperature sensor of Negative Temperature Coefficient (NTC)-type thermistor 503 ET-3H [14]. Therefore, this study could help women to predict their ovulation days and tell whether they are pregnant or not. Besides, the information of the BBT data can be shared with others like private specialist to get a fast consultation.

1.3 Problem statement

There are several commercial BBT devices in the market with the objective to help tracking and monitoring woman fertility with the ovulation chart. Nevertheless, most of the commercial body temperature measurement devices require users to plot their BBT chart manually and they have to understand the particular changes in the chart themselves or to establish several appointments with a healthcare specialist. Although there are several marketed BBT devices from overseas that automatically help charting, monitoring, and tracking the fertility with the help of digital applications, however most of them use different technologies such as Bluetooth and Universal Serial Bus (USB) to collect the BBT data. Besides, they do not have an assigned professional consultation that reduce their time-consuming to go see a doctor or physician. Furthermore, the imported BBT devices are lack of clinical study being reported on the algorithm used to derive the required information for fertility

prediction. Hence, through the development of TempIoT1.0 using a fuzzy logic computational intelligence method for the prediction of fertility conditions, and the IoT technology for the automatic BBT data charting, sharing and monitoring among the assigned physicians for further consultations, this will eventually help in improving the current practices of FAM.

1.4 Research objective

The aim of this research is to develop TempIoT1.0 prototype for an IoT based basal body temperature (BBT) measurement, automatic charting and monitoring, and smart fertility prediction using a fuzzy logic system. The objectives are:

(i) To design and develop a BBT measuring device using NTC-type thermistor sensor and Particle Photon microcontroller.

(ii) To design and develop an IoT based automatic BBT charting and monitoring, and smart fertility prediction using a fuzzy logic computational intelligence system integrated in Particle Photon.

(iii) To assess the efficiency of TempIoT1.0 for performance evaluation of the fertility prediction system and for performance evaluation using the BBT devices that are available in the market.

1.5 Research scope

There are some limitations from hardware and software used in this research project.

(i) The BBT measuring device was designed using Particle Photon microcontroller and a fast response time NTC-thermistor sensor for oral measurement of human's body temperature.

(ii) The BBT data was transmitted using the Wi-Fi internet network connection. This connection is between the BBT devices itself and the IoT clouds. A smartphone was used to monitor the BBT chart and to display the fertility prediction results using Android applications.

(iii) The fertility prediction of ovulation and pregnancy was designed using a fuzzy logic method through a MATLAB software with released name R2015b version 8.6 that was implemented in the Particle Photon.

(iv) The performance evaluation of the prediction system was determined based on 60 sample cycles of BBT online database from Fertility Friend website with exclude the sample background.

(v) The results from TempIoT1.0 were evaluated with two BBT devices available in the market that are Omron MC-272L Digital Basal Thermometer and the intelligent digital basal thermometer K021978 (iBasal) for the evaluation on its overall performance.

(vi) The results from LM35 sensor was evaluate with Tanita thermometer for the evaluation on ambient temperature.

(vii) The performance evaluation test was done on a healthy woman subject for the BBT measurement of three menstrual cycles.

1.6 Overall contribution

This research was focusing on an improvement of BBT based ovulation and pregnancy prediction system with IoT using fuzzy logic method. The system design and the development of the fuzzy logic fertility prediction system are important in this research to give a better performance in the fertility prediction to the user. The design and development of a BBT measuring device as an embedded IoT sensor with a high-accuracy performance is also one of the contributions in this research work. In this research, a prototype named TempIoT1.0 which among the first local based product was developed to help users measure the BBT automatically. TempIoT1.0 does the BBT charting automatically using IoT technology. Besides, TempIoT1.0 does monitor the BBT chart individually and indirect consultation with doctor through online data sharing of collected BBT data. It also does prediction of fertility conditions in order to help women understanding their unique menstrual cycle better. This research can improvise the BBT technique from FAM towards a better women's healthcare.

1.7 Thesis organisation

The thesis organisation is as follows. Chapter 2 concentrates on the information related to natural family planning, BBT device history, classification methods, hardware and software requirement and IoT technology, and the previous research works on healthcare monitoring.

In Chapter 3, the methodology and design strategies for this research was explained, starts with the description on the overall research framework and then, the explanation on the TempIoT1.0 prototype which consists of the hardware and software developments; the BBT measurement device development, the fuzzy logic fertility prediction system development, and the IoT platform and Android application development.

The explanation on the developed prototype of TempIoT1.0 includes the topics on the device prototype, IoT platform and Android applications was done in Chapter 4. The measurement and calibration results of the temperature sensor in the TempIoT1.0 prototype, the results on the verification of the fertility prediction system and the performance evaluation of TempIoT1.0 using the BBT devices available in the market are also discussed.

Lastly, in Chapter 5, the concluding remarks and future works was highlighted. Future suggestions for the TempIoT1.0 prototype, fuzzy fertility prediction system, and TempIoT1.0 IoT platform and Android application are also described.

REFERENCES

1. W. Chen, M. Kitazawa, and T. Togawa, "Identification of Biphasic Property in Female Menstrual Cycle from Oral, Skin and Core Body Temperatures," *IEEE Int. Conf. Inf. Technol. Appl. Biomed.*, pp. 1–4, 2010.
2. A. M. Rosliza and M. Majdah, "Male Participation and Sharing of Responsibility in Strengthening Family Planning Activities in Malaysia," *Malaysian J. Public Heal. Med.*, vol. 10, no. 1, pp. 23–27, 2010.
3. V. Kolici, E. Spaho, K. Matsuo, S. Caballe, L. Barolli, and F. Xhafa, "Implementation of a Medical Support System Considering P2P and IoT Technologies," *2014 Eighth Int. Conf. Complex, Intell. Softw. Intensive Syst.*, pp. 101–106, 2014.
4. G. Freundl, I. Sivin, and I. Batár, "State-of-the-art of non-hormonal methods of contraception: IV. Natural family planning.," *Eur. J. Contracept. Reprod. Health Care*, vol. 15, no. 2, pp. 113–23, Apr. 2010.
5. S. Oda, W. Chen, and M. Kitazawa, "BREW implementation of a mobile phone-based monitor for women's healthcare," *6th Int. Spec. Top. Conf. ITAB, 2007*, vol. 00, pp. 288–291, 2008.
6. Health Guides, "Medical Uses of the Birth Control Pill | Center for Young Women's Health," *Center for Young Women's Health*, 2014. [Online]. Available: http://youngwomenshealth.org/2011/10/18/medical-uses-of-the-birth-control-pill/. [Accessed: 27-Oct-2015].
7. R. S. H. Istepanian, S. Hu, N. Y. Philip, and a. Sungoor, "The potential of Internet of m-health Things m-IoT for non-invasive glucose level sensing," *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS*, pp. 5264–5266, 2011.
8. S. R. Pallone and G. R. Bergus, "Fertility Awareness-Based Methods: Another Option for Family Planning," *J. Am. Board Fam. Med.*, vol. 22, no. 2, pp. 147–157, 2009.
9. Y. S. Weng, "Wristwatch with Functions of Basal Body Temperature Charting

and Ovulation Phase Informing," 29-Apr-2004.

10. Vanessa Xi, "YONO Fertility Friend, a wearable basal thermometer," *KickStarter*, 2015. [Online]. Available: https://www.kickstarter.com/projects/1460153872/yono-fertility-friend-a-wearable-basal-thermometer/description. [Accessed: 26-Oct-2015].
11. Mazlan Abbas, "Internet of Things Journey The 3 Tsunamis of Internet," vol. 1, no. 1. FAVORIOT, pp. 15–19, 2017.
12. P. Gupta, D. Agrawal, J. Chhabra, and P. K. Dhir, "IoT based smart healthcare kit," *2016 Int. Conf. Comput. Tech. Inf. Commun. Technol. ICCTICT 2016 - Proc.*, pp. 237–242, 2016.
13. H. J. La, H. Ter Jung, and S. D. Kim, "Extensible disease diagnosis cloud platform with medical sensors and IoT devices," *Int. Conf. Futur. Internet Things Cloud, FiCloud 2015 2015 Int. Conf. Open Big Data, OBD 2015*, pp. 371–378, 2015.
14. ST Company, "Precision temperature sensors," *LM135-LM235-LM335 STMicroelectronics*, vol. 1, no. February, pp. 1–16, 2008.
15. Ripa Ajmera, "Introduction to Family Planning | LIVESTRONG.COM," *LiveStrong*, 2015. [Online]. Available: https://www.livestrong.com/article/72185-importance-family-planning/
16. M.T Mbzvio and S.J. Phillips, "Family planning: Choices and challenges for developing countries," *Res. Clin. Obstet. Gynaecol.*, vol. 28, no. 6, pp. 931–943, 2014.
17. C. Warniment and K. Hansen, "Is Natural Family Planning a Highly Effective Method of Birth Control? Yes: Natural Family Planning is Highly Effective and Fulfilling," *Am. Fam. Physician*, vol. 86, no. 10, pp. 1, 2012.
18. Hematram Yadav, "A review of maternal mortality in Malaysia A review of maternal mortality in Malaysia," *Int. eJournal Sci. Med. Educ.*, vol. 6, no. 1, pp. 142–151, 2012.
19. S. Achanna, G. Krishnaswamy, P. Ponnampalam, and A. Bondhu, "Maternal Mortality in Malaysia : Progress Made Towards Millennium Development Goal (MDG) 5 – An Analysis of Published Data," *Knowl. Enterp. Inc. Journals*, vol. 6, no. 2, pp. 1–14, 2018.
20. Ho Mei Kei, "Statistics on Causes of Death," *Popul. Demogr.*, vol. 6, no. 1, pp. 5–9, 2017.

21. A. August Burns, R. Lovich, J. Maxwell, and K. Shapiro, "Family Planning Methods," *Where Women Have No Doctor*, 1st ed., Berkeley, CA: Hesperian Health Guides, 2006, pp. 196–227.
22. Stephen Mark, "Natural Family Planning," *Family Doctor.org*, 2010. [Online]. Available: http://familydoctor.org/familydoctor/en/prevention-wellness/sex-birth-control/birth-control/natural-family-planning.printerview.html. [Accessed: 25-Nov-2015].
23. P. Frank-Herrmann, J. Heil, C. Gnoth, E. Toledo, S. Baur, C. Pyper, E. Jenetzky, T. Strowitzki, and G. Freundl, "The effectiveness of a fertility awareness based method to avoid pregnancy in relation to a couple's sexual behaviour during the fertile time: a prospective longitudinal study.," *Hum. Reprod.*, vol. 22, no. 5, pp. 1310–9, 2007.
24. "Fertility Awareness: Natural Family Planning (NFP)," *American Pregnancy Association*, 2015. [Online]. Available: http://americanpregnancy.org/preventing-pregnancy/natural-family-planning/. [Accessed: 26-Oct-2015].
25. Family Planning Western Australia, "Fertility Awareness Methods," pp. 239–254, 2012.
26. M. Owen, "Physiological Signs of Ovulation and Fertility Readily Observable by Women," *Linacre Q.*, vol. 80, no. 1, pp. 17–23, 2013.
27. H.-W. Su, Y.-C. Yi, T.-Y. Wei, T.-C. Chang, and C.-M. Cheng, "Detection of ovulation, a review of currently available methods," *Bioeng. Transl. Med.*, no. December 2016, pp. 238–246, 2017.
28. Deanna Day (2014). *Fevers, Fertility, and The Patient Labor of American Medicine*. Faculties of the University of Pennsylvania, Bloomington, Indiana, United States: Master's Thesis.
29. A. R. Martinez, M. H. A. Van Hooff, E. Schoute, M. Van Der Meer, F. J. M. Broekmans, and P. G. A. Hompes, "The reliability, acceptability and applications of basal body temperature (BBT) records in the diagnosis and treatment of infertility," *Eur. J. Obstet. Gynecol. Reprod. Biol.*, vol. 47, no. 92, pp. 121–127, 1992.
30. Theodore Zuck, "The relation of basal body temperature to fertility and sterility in women," *Am. J. Obstet. Gynecol.*, vol. 36, no. 38, pp. 998–1005, 1938.
31. Pendleton Tompkins, "The Use of Basal Temperature Graphs in Determining

the Date of Ovulation," *J. Am. Med. Assoc.*, vol. 11, no. 124, pp. 698–700, 1944.

32. Debbie Allen, "Determine Ovulation with Basal Body Temperature," *Denver Nutr.*, vol. 1, no. 1, pp. 1–5, 2016.
33. Isometrik, "MenstrualCycle2," *Wikimedia*. [Online]. Available: https://commons.wikimedia.org/wiki/File:MenstrualCycle2_en.svg. [Accessed: 30-Nov-2015].
34. Fertility Friends, "A brief history of fertility charting," *Fertility Friend*, 2015. [Online]. Available: http://www.fertilityfriend.com/Faqs/A-brief-history-of-fertility-charting.html. [Accessed: 01-Dec-2015].
35. Renee Brown-Bryant, Lee Warner, and Kelly Brumbaugh, "Infertility Fact," *Womens Heal.*, vol. 1, no. 1, pp. 1–5, 2015.
36. E. Setiawati, Adiwijaya, and A. B. W. Tjokorda, "Particle Swarm Optimization on Follicles Segmentation to Support PCOS Detection," *2015 3rd Int. Conf. Inf. Commun. Technol. ICoICT 2015*, pp. 369–374, 2015.
37. C. H. Vinkers, R. Penning, J. Hellhammer, J. C. Verster, J. H. G. M. Klaessens, B. Olivier, and C. J. Kalkman, "The effect of stress on core and peripheral body temperature in humans," *Stress*, vol. 16, no. 5, pp. 520–530, 2013.
38. C. Kresser and L. Schoenfeld, "Adrenal PCOS: Surprising Ways Stress Affects Your Hormones," *Health (Irvine. Calif).*, vol. 1, no. 3, pp. 7–13, 2016.
39. N. S. Ajmani, V. Sarbhai, N. Yadav, M. Paul, A. Ahmad, and A. K. Ajmani, "Role of Thyroid Dysfunction in Patients with Menstrual Disorders in Tertiary Care Center of Walled City of Delhi," *J. Obstet. Gynecol. India*, vol. 66, no. 2, pp. 115–119, 2016.
40. N. R. Ukibe, S. N. Ukibe, O. F. Emelumadu, C. C. Onyenekwe, J. E. Ahaneku, A. O. Igwegbe, I. N. Monago, and A. L. Ilika, "Impact of thyroid function abnormalities on reproductive hormones during menstrual cycle in premenopausal HIV infected females at NAUTH, Nnewi, Nigeria," *PLoS One*, vol. 12, no. 7, p. e0176361, 2017.
41. Olive Duddy, "Ideology and Development of NFP," *Cathol. Med. Assoc.*, vol. 65, no. 2, pp. 1–5, 2015.
42. John Marshall, "A Field Trial of The Basal Body Temperature Method of Regulating Births," *Lancet*, vol. 292, no. 7558, pp. 8–10, Jul. 1968.
43. Antonio R. Martinez, Marcel H.A van Hooff, Erik Schoute, Maartje van der Meer, Frank J.M. Broekmans, and Peter G.A. Hompes, "The Relability,

Acceptability and Applications of BBT Records in the Diagnosis and Treatment of Infertility," *Eur. J.*, vol. 47, no. 01425, pp. 121–127, 1992.

44. Bernie O'Hara, "The Development of NFP | Natural Family Planning Teachers Association of Ireland (NFPTAI)," *Natural Family Planning Teachers Association of Ireland (NFPTAI)*, 2014. [Online]. Available: http://www.naturalfamilyplanning.ie/the-development-of-nfp/. [Accessed: 30-Nov-2015].
45. J. M. S. Pearce, "A brief history of the clinical thermometer," *QJ Med*, vol. 95, no. 1915, pp. 251–252, 2002.
46. Alicia M. Prater, "The History of the Body Temperature Thermometer," *ActforLibraries.org*, 2015. [Online]. Available: http://www.actforlibraries.org/the-history-of-the-body-temperature-thermometer/. [Accessed: 01-Dec-2015].
47. Jennifer Aldoretta, *The Cycle*, 1st ed. Austin, Texas: Leanpub, 2014.
48. Yoseph Bar-Cohen, *Biologically Inspired Technologies*, 1st ed., vol. 13. United Kingdom: CRC Press Taylor & Francis Group, 2005.
49. Y. S. Weng, "Wristwatch with function of basal body temperature charting and ovulation phase informing," 2004.
50. Danielle Stratford, "Kindara Wink Thermometer Review - Appleseed Fertility," *AppleSeed Fertility*, 2014. [Online]. Available: http://www.appleseedfertility.com/blog/kindara-review. [Accessed: 21-Dec-2015].
51. S. Catherine, "Tempdrop Is A Wearable Body Temperature Sensor For Fertility Tracking," *TC Crunch Network*. [Online]. Available: http://techcrunch.com/2014/04/11/tempdrop-is-a-wearable-body-temperature-sensor-for-fertility-tracking/. [Accessed: 27-Oct-2015].
52. R. Paul, "Advanced fertility system offers money back pregnancy guarantee," *Gizmag*, 2010. [Online]. Available: http://www.gizmag.com/duofertility-ovulation-temperature-monitoring-system/16718/. [Accessed: 15-Oct-2015].
53. B. Sarah, "Ava Is A Bracelet That Aims To Predict The Most Likely Days For Women To Get Pregnant," *Techcrunch*, London, p. 1, Sep-2015.
54. M. Epstein, I. Emri, P. Hartemann, P. Hoet, N. Leitgeb, L. M. Martinez, A. Proykova, and L. Rizzo, *Potential health effects of exposure to electromagnetic fields (EMF)*, 1st ed., no. January. European Commission, 2015.

55. I. Thermometer, “Proper use of thermometers to measure body temperature,” *Med. Device*, vol. 4, no. 21, pp. 2–3, 2012.
56. G. C. Wolf and C. A. Baker, “Tympanic Thermometry for Recording Basal Body Temperatures,” *Fertil. Steril.*, vol. 60, no. 5, pp. 922–925, 1993.
57. G. Kelly, “Body temperature variability (Part 1): A review of the history of body temperature and its variability due to site selection, biological rhythms, fitness, and aging.,” *Altern. Med. Rev.*, vol. 11, no. 4, pp. 278–293, 2006.
58. M. L. Barron, R. Fehring, B. Mary, L. Barron, and R. J. Fehring, “Basal Body Temperature Assessment : Is It Useful to Couples Seeking Pregnancy ?,” *Am. J. Matern. Child Nurs.*, vol. 30, no. 5, pp. 290–296, 2005.
59. Belle Lilas, “Ovulation chart: How to predict ovulation by charting your basal body temperature and cervical mucus | BabyCenter,” *Baby Center*, 2010. [Online]. Available: http://www.babycenter.com/ovulation-chart. [Accessed: 22-Dec-2015].
60. Morrison, “How to Calculate Your Ovulation Period Using Your Menstrual Cycle,” *WeHaveKids*, California, pp. 1–6, Mar-2018.
61. Ariff Farhan Zainodin, “Fuzzy Logic System For Menstrual Cycle Interpretation Based On Bbt Data,” Universiti Tun Hussein Onn Malaysia, 2017.
62. M. S. M. Yazed, A. F. Zainodin, and F. Mahmud, “Fuzzy logic system for menstrual cycle interpretation based on BBT data,” *Int. J. Integr. Eng.*, vol. 9, no. 4, 2017.
63. M. Watanabe, Y. Nakamura, C. Tomiyama, and T. Abo, “A Specific Pattern in the Basal Body Temperature Chart during the First Week of Pregnancy May Warn of a Miscarriage Crisis,” *Health (Irvine. Calif).*, vol. 1, no. May, pp. 723–729, 2016.
64. Keith D. Foote, “A Brief History of the Internet of Things,” *Dataversity*, vol. 1, no. 1, p. 4, 2016.
65. K. L. Leuth, “Why the Internet of Things is called Internet of Things : Definition , history , disambiguation,” *IOT Anal.*, vol. 1, no. 12, p. 1, 2015.
66. Kim Baroudy, Sunil Kishore, Sumesh Nair, Mark Patel, “Unlocking value from IoT connectivity : Six considerations for choosing a provider,” *McKinsey Co.*, vol. 3, no. 1, pp. 2–15, 2018.
67. P. C. Evans and M. Annuziata, “Industrial Internet : Pushing the Boundaries of

Minds and Machines," *Imagination at Work*, vol. 1, no. 1, pp. 13–37, 2012.

68. H. L. Hao Chen, Xueqin Jia, "A Brief Introduction to IoT Gateway," *Proceeding of ICCTA*, vol. 7, pp. 5–8, 2011.
69. C. Bude, A. Kervefors, C. Bude, and A. Kervefors, "Internet of Things Internet of Things Exploring and Securing a Future Concept Industrial adviser," KTH Royal Institute of Technology, 2015.
70. R. S. H. Istepanian, A. Sungoor, A. Faisal, and N. Philip, "Internet of M-health Things 'm-IOT,'" *IET Semin. Assist. Living 2011*, pp. 20–20, 2011.
71. K. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," *IEEE Access*, vol. 3, 2015.
72. A. Papageorgiou, B. Cheng, and E. Kovacs, "Reconstructability-Aware Filtering and Forwarding of Time Series Data in Internet-of-Things Architectures," *2015 IEEE Int. Congr. Big Data*, pp. 576–583, 2015.
73. S. Peppet, "Regulating the Internet of things: First steps toward managing discrimination, privacy, security, and consent," *Tex. Law Rev.*, vol. 93, no. 1, pp. 85–176, 2014.
74. S. Sumathi and S. Paneerselvam, "Types of Membership Functions," in *Computational Intelligence Paradigms Theory and Applications*, London, Boca Raton, New York: Taylor and Francis Group, LLC, 2010, pp. 200–220.
75. E. Funes, Y. Allouche, G. Beltrán, and A. Jiménez, "A Review: Artificial Neural Networks as Tool for Control Food Industry Process," *J. Sens. Technol.*, vol. 05, no. 01, pp. 28–43, 2015.
76. R. Seising, "When Computer Science Emerged and Fuzzy Sets Appeared," *IEEE Systems, Man, & Cybernetics Magazine*, no. 1, pp. 1–18, Mar-2016.
77. Archana L. Rane, "Clinical Decision Support Model for Prevailing Diseases to Improve Human Life Survivability," in *International Conference on Pervasive Computing (ICPC) Clinical*, 2015, vol. 15, no. 1, pp. 1–5.
78. R. Seising, "Fuzzy Sets: A New View on System Theory," *NAFIPS 2005 - 2005 Annu. Meet. North Am. Fuzzy Inf. Process. Soc.*, pp. 92–97, 2005.
79. Lotfi Aliasker Zadeh, "Biological application of the theory of fuzzy sets and sytems," *Process International Symposium Biocybernetics of the Central Nervous System*. Boston, pp. 199–212, 1969.
80. Professor Janusz Kacprzyk, Senen Barro, and Roque Marin, Eds., *Fuzzy Logic in Medicine*, First. Spain: Physica-Verlag, 2002.

81. N. N. Prince and N. Ifeanyi, “Application of Fuzzy Logic Control in Design and Implementation of Digital Egg Incubator,” *Int. J. Comput. Sci. Technol.*, vol. 2, no. 1, pp. 161–164, 2011.
82. J. V. Dos Reis, T. R. Raddo, A. L. Sanches, and B. H. V. Borges, “Comparison between Mamdani and Sugeno fuzzy inference systems for the mitigation of environmental temperature variations in OCDMA-PONs,” *Int. Conf. Transparent Opt. Networks*, vol. 2015–Augus, pp. 8–11, 2015.
83. R Akerkar, P Sajja, and Ashique Rasool, “Fuzzy Logic,” SlideShare, Saudi Arabia, pp. 1–23, 2006.
84. Particle company, “The Guide: Introduction to the Guide,” *Particle docs*, 2017. [Online]. Available: https://docs.particle.io/guide/getting-started/intro/photon/.
85. C. V. R. Steffen Rudtsch, “How - to Guide for Most Common Measurement,” *Temp. Meas. with Thermistors*, no. 3, pp. 1–3, 2016.
86. Acromag, “Criteria for Temperature Sensor Selection of T/C and Rtd Sensor Types,” no. May, pp. 1–14, 2011.
87. J. M. L. P. Caldeira, J. J. P. C. Rodrigues, J. F. R. Garcia, and I. de la Torre, “A New Wireless Biosensor for Intra-Vaginal Temperature Monitoring,” *Sensors*, vol. 10, no. 11, pp. 10314–10327, 2010.
88. Semitec, “ET Thermistor Series (fast response time type),” Tokyo, 2015.
89. Texas Instrument, “LM35 Precision Centigrade Temperature Sensors,” 2016.
90. Dmitry Galkin, “Master ’ s Thesis Design and development of hardware and software for wireless Head-Mounted Displays,” University of Bremen, 2015.
91. Particle company, “Flash Apps with Particle Build,” *Particle docs*, 2017. [Online]. Available: https://docs.particle.io/guide/getting-started/build/photon/.
92. I. Mathworks, “MathWorks Announces Release 2013b of the MATLAB and Simulink Product Families,” *MathWorks*, pp. 1–3, 2013.
93. Mathworks Inc, “Platform Road Map for the MATLAB Product Families,” Natick, Massachusetts, United States, 2018.
94. Mathworks, *Fuzzy Logic Toolbox ™ User ’ s Guide R 2019 b*, Online edi. Natick, Massachusetts, United States: Mathworks, 2019.
95. N. Gupta, “Comparative Study of type-1 and Type-2 Fuzzy Systems,” vol. 2, no. 4, pp. 195–198, 2014.
96. Dragan Z. Saletic, Dusan M. Velasevic, and Nikos E. Mastorakis, “Analysis of Basic Defuzzification Techniques,” *6th WSES Int. Multiconference Circuits*,

Syst. Commun. Comput., vol. 1, no. September, pp. 2–7, 2002.

97. J. J. Saade and H. B. Diab, "Defuzzification Methods and New Techniques for Fuzzy Controllers," *Iran. J. Electr. Comput. Eng.*, vol. 3, no. 2, pp. 161–174, 2004.
98. Sculpteo Company, "Solidworks tutorial: Prepare your model for 3D printing with SolidWorks," *Solidworks Tutorial*, 2014. [Online]. Available: https://www.sculpteo.com/en/tutorial/prepare-your-model-3d-printing-solidworks/modeling-3d-printing-solidworks/.
99. SolidWorks Corporation, "The Future of 3D Printing," *Resource Center*, 2018. [Online]. Available: https://www.solidworks.com/sw/resources/future-3d-printing.htm. [Accessed: 20-Aug-2009].
100. Labcenter Electronics Ltd, "Proteus Design Suite Overview," *Proteus*, 2016. [Online]. Available: https://www.labcenter.com/.
101. PushingBox, "PushingBox - Notifications for your Internet of Things devices," *PushingBox*, 2014. [Online]. Available: https://www.pushingbox.com/.
102. Neil Patel, "25 Awesome Free Google Tools for Marketers," *neilpatel.com*, 2019. [Online]. Available: https://neilpatel.com/blog/25-awesome-google-tools/.
103. D. M. M. Pacis, E. D. C. S. Jr., and N. T. Bugtai, "Trends in telemedicine utilizing artificial intelligence Trends," in *2nd Biomedical Engineering's Recent Progress in Biomaterials, Drugs Development, and Medical Devices*, 2018, vol. 1933, no. February, pp. 1–10.
104. B. Nagarajan, S. Jadhav, P. Desai, K. Amberkar, and A. Dandekar, "Supervising Real Time Vital Signs of a Patient," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 5, no. 4, pp. 1041–1044, 2017.
105. T. Magano, K. Djouani, A. M. Kurien, and A. Chibani, "A Fuzzy based Diagnostic Agent for Context Aware Patient Monitoring," *Procedia Comput. Sci.*, vol. 141, pp. 421–427, 2018.
106. E. Berglund Scherwitzl, K. Gemzell Danielsson, J. A. Sellberg, and R. Scherwitzl, "Fertility awareness-based mobile application for contraception," *Eur. J. Contracept. Reprod. Heal. Care*, vol. 21, no. 3, pp. 234–241, 2016.
107. S. Reddy, J. Fox, and M. P. Purohit, "Artificial intelligence-enabled healthcare delivery," *J. R. Soc. Med.*, vol. 1, no. 1, pp. 1–7, 2018.
108. S. Sweidan, S. El-sappagh, H. E. S. Sabbeh, and F. A. B. K. Kwak, "A Fibrosis

Diagnosis Clinical Decision Support System Using Fuzzy Knowledge," *Arab. J. Sci. Eng.*, vol. 44, no. 4, pp. 3781–3800, 2018.

109. S. Mishra and M. Prakash, "Study of Fuzzy Logic in Medical Data Analytics," *Int. J. Pure Appl. Math.*, vol. 119, no. 12, pp. 16321–16342, 2018.
110. N. Sehatbakhsh, M. Alam, A. Nazari, A. Zajic, and M. Prvulovic, "Syndrome: Spectral analysis for anomaly detection on medical IoT and embedded devices," *2018 IEEE Int. Symp. Hardw. Oriented Secur. Trust*, pp. 1–8, 2018.
111. A. Rashed, A. Ibrahim, A. Adel, B. Mourad, A. Hatem, M. Magdy, N. Elgaml, and A. Khattab, "Integrated IoT Medical Platform for Remote Healthcare and Assisted Living," *JAC-ECC*, pp. 160–163, 2017.
112. G. Corotinschi and V. G. Gaitan, "The use of IoT technologies for providing high-quality medical services," *Int. Conf. Syst. Theory, Control Comput. ICSTCC 2017*, pp. 285–290, 2017.
113. P. P. Shinde, K. S. Oza, and R. K. Kamat, "Big data predictive analysis: Using R analytical tool," *2017 Int. Conf. I-SMAC (IoT Soc. Mobile, Anal. Cloud)*, pp. 839–842, 2017.
114. L. E. Romero, P. Chatterjee, and L. E. Romero, "An IoT approach for integration of computational intelligence and wearable sensors for Parkinson ' s disease diagnosis and monitoring," *Health Technol. (Berl).*, pp. 1–6, 2016.
115. A. H. T. E. De Silva, W. H. P. Sampath, N. H. L. Sameera, Y. W. R. Amarasinghe, and A. Mitani, "Development of a wearable tele-monitoring system with IoT for bio-medical applications," *2016 IEEE 5th Glob. Conf. Consum. Electron. GCCE 2016*, vol. 1, no. 1, pp. 4–5, 2016.
116. D. Azariadi, V. Tsoutsouras, S. Xydis, and D. Soudris, "ECG signal analysis and arrhythmia detection on IoT wearable medical devices," *2016 5th Int. Conf. Mod. Circuits Syst. Technol. MOCAST 2016*, pp. 1–4, 2016.
117. E. Berglund, K. Gemzell, J. A. Sellberg, and R. Scherwitzl, "Fertility awareness-based mobile application for contraception," *Eur. J. Contracept. Reprod. Heal. Care*, vol. 21, no. 3, pp. 234–241, 2016.
118. M. Syukri, M. Yazed, and F. Mahmud, "RFID-based Interactive Log Bag for Poor Memory Prevention," *Int. J. Integr. Eng.*, vol. 8, no. 1, pp. 59–63, 2016.
119. P. Toumieux, S. Sahuguède, L. Chevalier, and A. Julien-Vergonjanne, "Optical wireless connected objects for healthcare," *Healthc. Technol. Lett.*, vol. 2, no. 5, pp. 118–122, 2015.

120. J.-H. Kim, S.-C. Lee, B.-G. Lee, and W.-Y. Chung, “Mobile Healthcare System Based on Bluetooth Medical Device,” *J. Sens. Sci. Technol.*, vol. 21, no. 4, pp. 241–248, 2012.

121. J. H. T. Bates and M. P. Young, “Applying Fuzzy Logic to Medical Decision Making in the Intensive Care Unit,” *Am. J. Respir. Crit. Care Med.*, vol. 167, no. 1, pp. 948–952, 2003.

122. G. Recktenwald, “Temperature Measurement with a Thermistor and an Arduino,” *Pdx.Edu*, 2013.

123. W. Storr, “Resistors in Series - Series Connected Resistors,” *Basic Electronics Tutorials Site*, 1999. [Online]. Available: http://www.electronics-tutorials.ws/resistor/res_3.html. [Accessed: 22-Dec-2015].

124. J. S. Steinhart and S. R. Hart, “Calibration curves for thermistors,” *Deep Sea Res. Oceanogr. Abstr.*, vol. 15, no. 4, pp. 497–503, 1968.

125. A. J. Wilcox, D. Dunson, and D. D. Baird, “The timing of the ‘fertile window’ in the menstrual cycle: day specific estimates from a prospective study,” *Bmj*, vol. 321, pp. 1259–1263, 2000.

126. Mrs. Colleen Norman B.A., “Guidelines to Charting Your Fertility Cycle,” *Fertil. Educ. Train.*, vol. 1, no. 1, pp. 3–4, 2011.

127. C. Stephens, “What Is the Normal Body Temperature Range?,” *Heal. Line*, vol. 1, no. 1, pp. 1–2, 2018.

128. N. M. Crawford, D. A. Pritchard, A. H. Herring, Z. Anne, C. Hill, and C. Hill, “A prospective evaluation of luteal phase length and natural fertility,” *Fertil Steril*, vol. 107, no. 3, pp. 749–755, 2018.

129. M. C. Koch, J. Lermann, N. Van De Roemer, S. K. Renner, S. Burghaus, J. Hackl, R. Dittrich, S. Kehl, P. G. Oppelt, T. Hildebrandt, C. C. Hack, U. G. Pöhls, S. P. Renner, and F. C. Thiel, “Improving usability and pregnancy rates of a fertility monitor by an additional mobile application : results of a retrospective efficacy study of Daysy and DaysyView app,” *BioMed Cent.*, vol. 15, no. 37, pp. 1–10, 2018.

130. Fertilityfriend, “FertilityFriend . com ’ s Chart Gallery,” *FertilityFriend*, 2016. [Online]. Available: https://www.fertilityfriend.com/cg/.

131. J. Sorocki, S. Koryciak, I. Piekarz, S. Gruszczynski, and K. Wincza, “Investigation on Additive Manufacturing with Conductive PLA Filament for Realisation of Low- loss Suspended Microstrip Microwave Circuits,” *IEEE Int.*

Conf. Inf. Technol. Appl. Biomed., vol. c, pp. 48–51, 2017.

132. Fairhaven Health, “ibasal Thermometer Instructions,” Bellingham, Washington, 2013.